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TENTATIVE PROCEDURES FOR PARTICLE SIZING IN PROCESS STREAMS

CASCADE IMPACTORS

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TENTATIVE PROCEDURES FOR PARTICLE SIZING IN PROCESS STREAMS
Cascade Impactors

Industrial Environmental Research Laboratory
Office of Research and Development
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16. ABSTRACT: The report, in guideline form, is an outgrowth of discussions by members of a small group of EPA/IERL-RTP personnel, contractors, and independent experts who met to develop uniform procedures for the field use of inertial impactors to determine particle size distributions from industrial particulate sources. It is intended to promote individual tests of similar quality so that valid comparisons may be made. It is emphasized that this document is for guidance only, and is not a set of rules. Techniques for measuring particle size in stationary sources are too new, and too few testing situations are the same. Professional judgment is still the most important element in successfully determining fractional efficiency. The report discusses the preliminary survey, the sampling apparatus, testing procedures, and data analysis. The information applies to cascade impactors in general. Specific commercial impactors are discussed.

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TENTATIVE PROCEDURES FOR PARTICLE SIZING IN PROCESS STREAMS--CASCADE IMPACTORS

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1.0 INTRODUCTION

Inertial impactors are commonly used to determine the particle size distributions from industrial particulate sources. These impactors have several advantages over competing techniques: they are compact, can be inserted directly into the duct (avoiding the sample loss problems of a probe), and are fairly accurate. The Process Measurements Branch (PMB) of EPA's Industrial Environmental Research Laboratory, Research Triangle Park, N. C., has been using inertial impactors to determine fractional efficiency for several years, as have a number of IERL-RTP contractors. The PMB has also sponsored an evaluation of impactors to select devices that could be used under normal field conditions. During the course of these programs it became evident that no uniform approach to the field use of impactors was available.

To develop uniform procedures, a working group of IERL-RTP contractors, and independent experts met at Research Triangle Park, N.C. This guideline is an outgrowth of the working group discussions, and is intended to promote individual tests of similar quality so that valid comparisons may be made.

It is emphasized that this document is for guidance only, and is not a set of rules. Techniques for measuring particle size in stationary sources are too new, and too few testing situations are the same. There is unanimous concurrence that the present state of knowledge does not permit a routine procedure to be set forth. Therefore, professional judgment is still the most important element in successfully determining fractional efficiency.

The scope of this report includes the preliminary survey, the sampling apparatus, testing procedures, and data analysis. The information is applicable to cascade impactors in general. Specific commercial impactors are discussed in the section titled "Commercial Impactors."

2.0 THE PRESURVEY

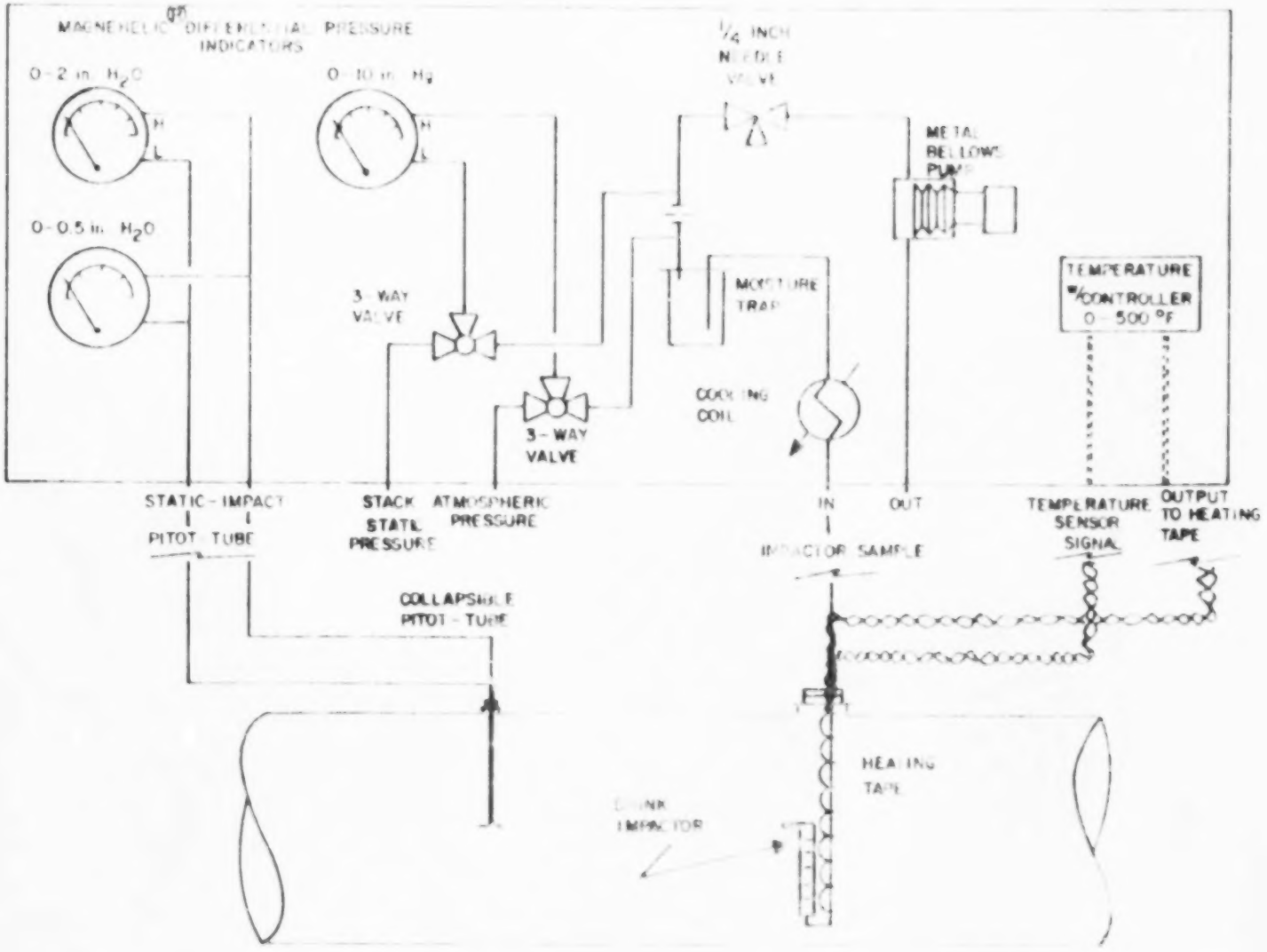
The key to performing a successful fractional efficiency evaluation is thorough planning based on a complete pretest site survey. During this survey, anything which could affect the testing program must be noted. The accessibility and suitability of sampling ports, platforms, and electrical power should be assessed. Requirements and provisions for any special adaptors or processes should be determined. A good guide is the presurvey form used by the Emissions Standards and Engineering Division (ESED) of EPA's Office of Air Quality Planning and Standards. A copy of this presurvey form has been included as Appendix D.

Other information which should be obtained during the presurvey includes preliminary data on flue gas temperatures, velocities, gas composition (CO_2, CO, H_2O, O_2, toxic and/or non-toxic vapors, etc.), and stack pressures. If possible, this data should be measured rather than obtained from plant records or personnel.

A good presurvey should also include estimates of particulate loading and size distributions. A few guide samples utilizing the Brink impactor as a screening device will provide this information. The sampling system shown in Figure 1 has been developed for presurvey sampling. A collapsible pitot probe with an attached thermocouple is used to determine stack gas velocity. Using the velocity information, a nozzle is selected for the Brink impactor which will produce approximately isokinetic conditions for the Brink sampling rate of 0.04 to 0.07 acfm*. The sample should be taken within ±20 percent of isokinetic conditions.

If preweighed substrates are used in the Brink, a fairly accurate picture of size distribution and mass loading can be developed. Very rough estimates can be obtained from visual inspection of the substrates if a balance is not available. Obtaining a particulate sample during the presurvey provides an opportunity for detection of possible trouble such as acid condensation, physical obstructions at sample stations, and process variability.

*Although it is EPA policy to use metric units in all documents it produces, this report includes certain non-metric units for convenience. Readers more familiar with the metric system may use the factors in Appendix G for conversion.


MAGNEHELIC DIFFERENTIAL PRESSURE INDICATORS
0-2 in. H_2O
0-10 in. Hg
0-0.5 in. H_2O
1/4 INCH NEEDLE VALVE
METAL BELLOWS PUMP
3-WAY VALVE
MOISTURE TRAP
COOLING COIL
3-WAY VALVE
TEMPERATURE CONTROLLER 0-500 °F
STATIC-IMPACT PITOT TUBE
STACK STATIC PRESSURE
ATMOSPHERIC PRESSURE
IN
OUT
TEMPERATURE SENSOR SIGNAL
OUTPUT TO HEATING TAPE
IMPACTOR SAMPLE
COLLAPSIBLE PITOT-TUBE
HEATING TAPE
IMPACTOR

In summary, the presurvey should provide the information necessary to design an adequate test program. The decisions which must be made are summarized in Table 1.

Table 1. IMPACTOR DECISION MAKING

Item	Information Required	Criteria
Impactor	Loading and size estimate	a. If less than 0.2 grain of particles/acf is smaller than 5.0 μm, use high flow rate impactor b. If greater than 0.2 grain of particles/acf is smaller than 5.0 μm, use low flow rate impactor
Sampling rate	Loading and gas velocity	a. Fixed, near isokinetic b. Limit so last jet velocity does not exceed: -60 m/sec greased -35 m/sec without grease
Nozzle	Gas velocity	a. Near isokinetic b. Sharp edged; min 2.0 mm
Pre-cutter	Size and loading	If pre-cutter loading is comparable to first stage loading--use pre-cutter
Sampling time	Loading and flow rate	a. Per Figure 3 b. No stage loading greater than 10 mg
Collection substrates	Temperature and gas composition	a. Use metallic foil or fiber substrates whenever possible b. Use adhesive coatings whenever possible
Number of sample points	Velocity distribution and duct configuration	a. At least two points per station b. At least two samples per point

Table 1 (cont'd). IMPACTOR DECISION MAKING

Item	Information Required	Criteria
Orientation of impactor	Duct size, port configuration, and size	Vertical impactor axis wherever possible
Heating	Temperature and condensible vapors	a. If flue is above 350°F, sample at process temperature b. If flue is below 350°F, sample at 20°F above process temperature at impactor exit using external heaters.
Probe	Port not accessible using normal techniques	a. Only if absolutely necessary b. Pre-cutter on end c. Minimum length and bends possible

3.0 EQUIPMENT SELECTION AND PREPARATION

3.1 IMPACTOR SELECTION

The selection of the proper impactor for a particulate test situation is primarily dependent upon the mass loading of the gas stream and its effect on sampling time. There are three major criteria to be met to match an impactor to a particulate stream:

1) The sampling period must be long enough to provide a reasonable averaging of any short term transients in the stack.

2) The maximum allowable loading on a given impactor stage is about 10 mg.

3) The sampling rate through the impactor must be low enough to prevent scouring of impacted particles by high gas velocities.

For these reasons, an impactor with a comparatively low sample rate must be used in a gas stream with a high mass loading. The low sample rate allows a longer sampling time, although in some situations it will still be undesirably short. The Brink impactor is an example of a low flow rate impactor.

Conversely, in a low mass loading situation such as a control device outlet, a high sample rate device must be used if a significant amount of sample is to be gathered in a reasonable amount of time. The Andersen Mark III and the Pilat (University of Washington) Mark III impactors are examples of high sample rate devices.

A cascade impactor can normally yield useful information over a range of sample rates differing by a factor of 2 or 3. As high efficiency control devices cause the outlet mass loading to differ from the inlet by a factor of ten, the same impactor cannot be used on both inlet and outlet. Both high and low flow rate impactors are required to determine the efficiency of most particulate control devices.

3.2 NUMBER OF SAMPLE POINTS

As the velocity and particulate distributions in industrial ductwork are unlikely to be ideal, a large number of samples are required for accurate particulate measurements. At least two points within a duct should be sampled in each measurement plane, and at least two samples taken at each of these points. These are minimum sampling efforts and

are appropriate only for locations with well developed flow profiles and consistent mass loadings. If the flow profile at the station is uncertain due to duct configuration and/or the mass loading is not uniform, the number of samples must be increased for reliable results.

3.3 IMPACTOR ORIENTATION

Whenever possible, the impactor should be oriented vertically to minimize gravitational effects such as flow of grease or fall-off of collected particles. Sampling situations requiring horizontal placement will occur and extra care must be taken on such occasions not to bump the impactor against the port during removal.

3.4 HEATING IMPACTOR

All condensible vapors must be in a gaseous state until they exit from the impactor, unless a condensate is the prime aerosol being measured. In gas streams above 350°F, auxiliary heating should not be required. Below 350°F the exit temperature of the impactor should be maintained at least 20°F above the process temperature. (A thermocouple feedback temperature controller has proven useful.)

Whether the impactor is being heated in the duct or externally with heater tape, an allowance of 30 minutes warm-up time is recommended as a minimum to ensure that the impactor has been heated to duct or operating temperature. High mass units such as the Brink may require 45 minutes. Thermocouple monitoring of the impactor temperature and impactor exit gas temperature is recommended.

3.5 PROBES

Sampling probes leading to an impactor outside of the duct should be used only if there is no other way. They should be as short as possible and contain the fewest possible bends. It is recommended that a pre-cutter be mounted at the duct end of the probe to remove the large particles and thus reduce line losses.

3.6 NOZZLE AND SAMPLING RATE SELECTION

It is preferable to use as large a nozzle diameter as possible to minimize sampling errors resulting from nozzle inlet geometry. When very small nozzles have been used with the Brink impactor, there have been some cases in which large amounts of material were retained in the nozzle or the nozzle was completely blocked. It is recommended that

the nozzle not be smaller than 2.0 mm. In some instances bent nozzles are necessary due to port location and gas direction, but these should be avoided. Problems occur in cleaning bent nozzles, and it is difficult to determine the size interval in which the deposited material originated. If they cannot be avoided, bends should be as smooth as possible and of large radius in order to minimize the losses in the fine particulate region.

The sampling rate must be such that the last stage velocity does not exceed 60 m/sec for greased collection surfaces or 30 m/sec for ungreased plates if no suitable substrate can be found to limit particle bounce. The flow rates above should not be considered the final word on nozzle velocity, as particle bounce has been observed at nozzle velocities as low as 10 m/sec. The exposed substrate should be visually examined for evidence of re-entrainment and the rates adjusted accordingly.

It is apparent that sample rate and nozzle size are closely coupled. The requirements for isokinetic or near-isokinetic nozzle flow sometimes impose a compromise on nozzle selection. The general order of priorities when choosing the sample rate is nozzle diameter (at least 2 mm), last stage jet velocity, and flow rate required for isokinetic sampling. Selection of nozzle diameter and impactor flow rate combinations for achieving near-isokinetic sampling conditions can be made from Figure 2. Note that the upper flow limits for some impactors have been indicated by horizontal lines at the appropriate flow rate.

3.7 PRE-CUTTER USE

In many instances the percentage (by weight) of material with sizes larger than the first impaction stage cut point is quite high. In such cases a precollector cyclone is necessary to prevent the upper impactor stages from overloading. A pre-cutter should always be used for the first test. If the weight of material obtained by the pre-cutter is comparable to that on the first stage, the precollector should be used in all subsequent runs. Cyclones can be obtained from the impactor manufacturer or can be shop made. A set of drawings of a cyclone for the Brink is included in Appendix B. The basic design can be adapted for attachment to other impactors. The use of two first stages in series has also been suggested and appears to be a valid approach; however, no data are available.

NOTE: HEAVY HORIZONTAL LINES INDICATE MAXIMUM FLOW RATES WITHOUT RE-ENTRAINMENT FOR VARIOUS IMPACTORS.

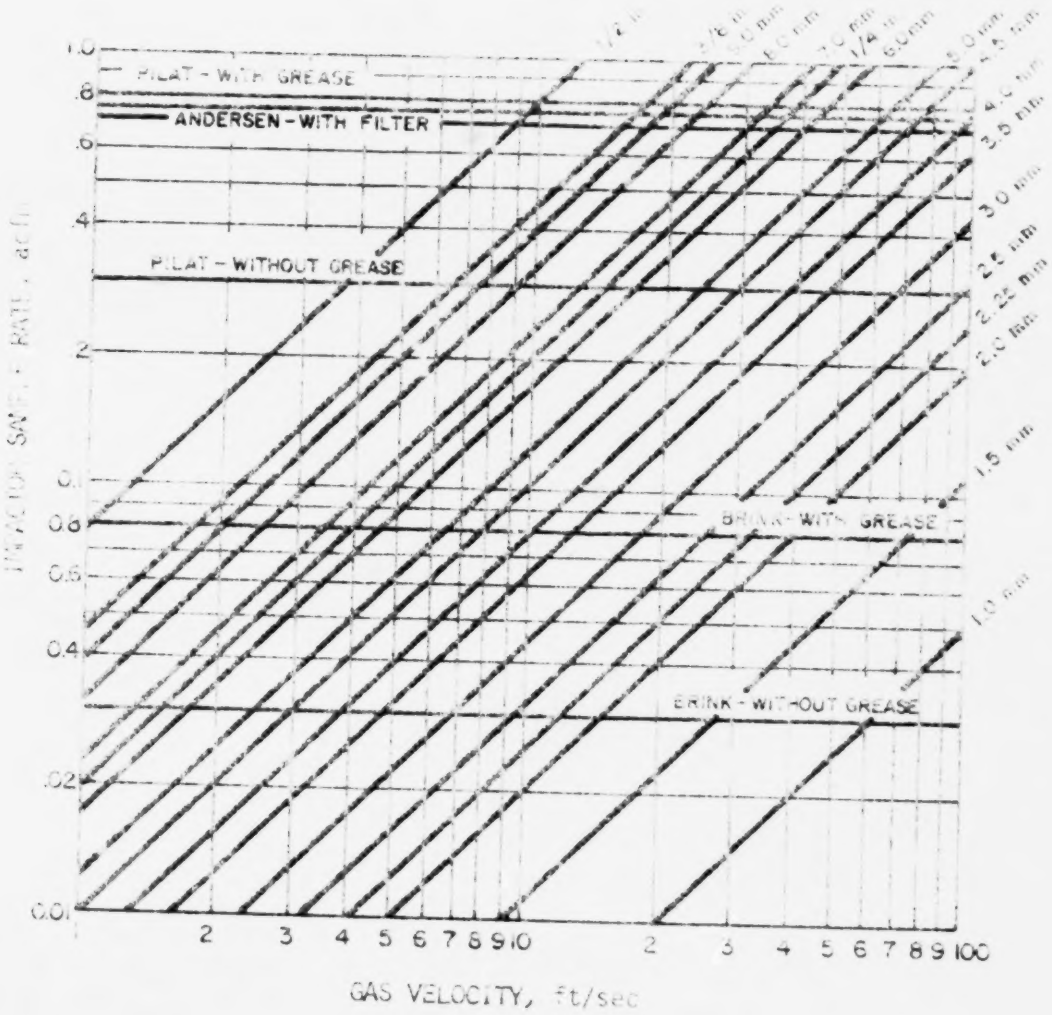


Figure 2. Nomograph for selecting nozzles for isokinetic sampling.

3.8 SAMPLING TIME

The length of the sampling time is dictated by mass loading and size distribution. An estimate for initial tests can be obtained from Figure 3. The duration of the following tests should be adjusted so that no single stage (excluding a pre-cutter if one is used) has more than 10 mg of sample.

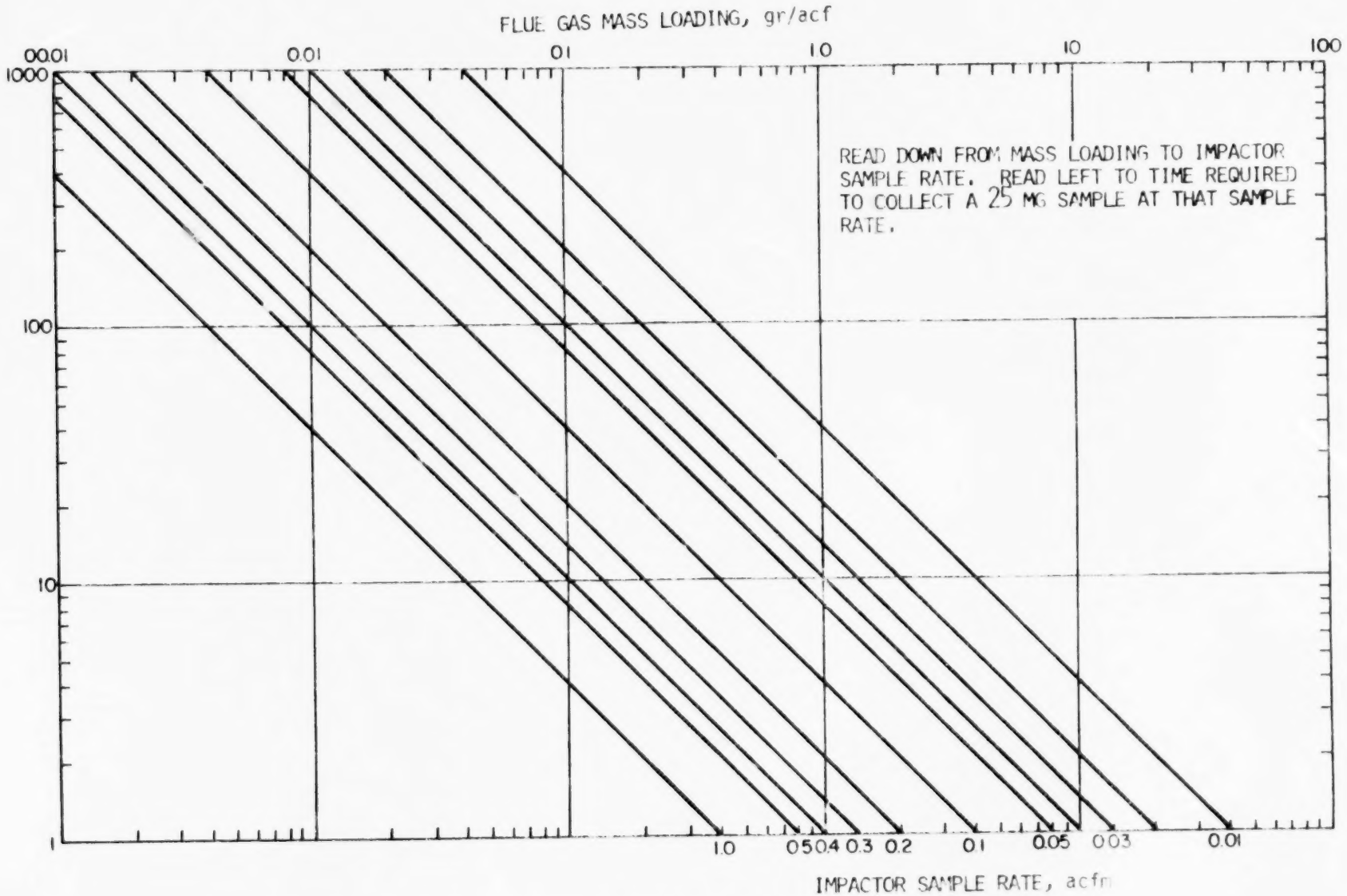


Figure 3. Nomograph for sampling time selection (25 mg sample).

4.0 COLLECTION SUBSTRATES AND ADHESIVES

4.1 COLLECTION SUBSTRATES

Due to the necessity of high weighing accuracy, large stage tare weights, and low tare capacity of most field useable precision balances, metal foil or glass fiber collection substrates should be used with all impactors. The Brink has generally been used with aluminum foil or, in some cases, glass fiber or Teflon substrates. The Andersen Mark III utilizes special glass fiber inserts supplied by the manufacturer, and the Pilat Mark III has been used with aluminum or stainless steel foil substrates.

Glass Fiber Substrates -- The use of the glass fiber substrates available for the Andersen is recommended. They are as resistant to particle loss as are greased substrates. Care must be taken when using glass fiber substrates in streams containing sulfur dioxide, however. Recent experimentation has shown that glass fiber materials sometimes show weight gains due to sulfate uptake on the substrates. Apparently, sulfur dioxide in a gas stream can react with basic sites on some glass fiber materials and form sulfates. Normal Andersen substrates have shown significant weight gains at times due to this reaction.

There are two approaches to this problem. Substrates which will gain weight from sulfate uptake can be preconditioned in the flue gas before weighing. From two to six hours of exposure to the flue gas is sufficient to use up all of the active sites and prevent weight gains. Another approach is to use a fibrous substrate which shows little weight gain in a sulfur dioxide stream. Some substances which have been tested and exhibit only slight weight gains are Teflon, Whatman GF/A and GF/D, and Reeve Angel 934 AH. It is not known whether these materials have the same particulate retention characteristics as do the more common substrates. The calibration of impactors used with these substrates might be changed some.

Greased Substrates -- Grease must often be used on the collection substrates of the Brink and Pilat impactors to aid in particle retention. The use of grease allows higher flow rates than are possible without grease. Flow rates as high as 60-65 m/sec have been used with greased substrates and acceptable results obtained.

A 20 percent solution of grease in benzene has been found suitable for placing the grease on the substrates. The solution is dropped onto the substrate with an eye dropper. A Pilat stage requires 7 or 8 drops while the last stages of a Brink only require one drop. Even less grease may be used if light stage loading is anticipated. After the proper amount of solution has been placed on the substrate, the greased substrates are baked at 400°F for 1 to 2 hours and then desiccated for 12 to 24 hours prior to weighing. Depending on the temperature in the sampling duct, a silicone or other high viscosity type of grease may be used on the substrates. Gas chromatographic material such as polyethylene glycol 600 has exhibited more consistent characteristics than materials such as stopcock grease. There have been cases of greased substrate losing weight in hot, dry gases and this possibility should be considered.

Horizontal operation of the impactors with greased substrates is not recommended due to possible flow of the grease. Care must also be taken to ensure that grease is not blown off the substrates (which tends to occur at jet velocities greater than 60 m/sec).

4.2 BACK-UP FILTERS

Back-up filters are used on all impactors to collect the material that passes the last impaction stage. Binderless glass fiber filter material (such as Gelman Type A Glass Fiber Filter Web) is used for this purpose in all of the impactors, although the exact configuration varies.

4.3 BALANCE REQUIREMENTS

For accurate weighing of collected material a balance with a sensitivity of at least 0.01 mg is required. This is especially true for the lower stages of the high loading impactors where collection of 0.3 mg or less is not uncommon. The balance must also be insensitive to vibration if it is to be used in the field. These capabilities are available in several electrobalances marketed in the U.S. It is also desirable to have a balance with a large enough weighing chamber to accommodate the Pilat foils without having to fold them.

4.4 SAMPLING TRAINS

The sampling trains for both the high and low flow impactors are very similar. They basically consist of a vacuum pump and flow measurement and control equipment. For long sampling times, or where there is high water content, a series of condensers in an ice bath are useful for removing the moisture. A drying column and cooling coil are recommended to follow the condensers. Examples of sampling trains for the various impactors are included in the appropriate impactor sections.

5.0 SAMPLING

5.1 READYING THE IMPACTOR

The impactor should be carefully loaded with the preweighed stage substrates and assembled. Antiseize compound should be applied to the threads especially when high temperatures (>400 F) are encountered. The appropriate nozzle is then attached.

If supplemental heating is required, the heating tapes, insulation, and temperature monitors need to be added. A thermocouple mounted in the gas flow immediately after the impactor is best for controlling heating. This also yields the temperature needed for calculating impactor cut points. A heating tape of sufficient wattage is wrapped around the impactor. Glass fiber tape works well for holding the heating tape. Insulation such as asbestos tape is then wound around the impactor. Glass fiber tape again is used to hold the asbestos in place and also acts as additional insulation. The impactor can now be mounted on the appropriate probe, taken to the sampling position, and installed in the sampling system.

5.2 TAKING THE SAMPLE

The impactor should be preheated for at least 45 minutes before sampling. If supplemental heat is being used, the impactor should be brought up to temperature outside the duct and then allowed some time to equilibrate after insertion. The nozzle should not point into the flow field during this phase. Without supplemental heat, the whole warm up is conducted within the duct, again with the nozzle pointed away from the flow field.

A predetermined flow rate must be maintained to ensure stable cut points. Any attempt to modulate flow to provide isokinetic sampling will destroy the utility of the data by changing the cut points of the individual stages. Rapid establishment of the correct flow rate is especially important for the short sampling times typically found at the inlets to control devices.

6.0 POST-SAMPLING PROCEDURE

6.1 IMPACTOR CLEAN-UP

The post-test procedure is very important in obtaining useful results. The crucial part is to make sure the collected material stays where it originally impacted. After the test, the impactor should be carefully removed from the duct without jarring, removed from the probe, and allowed to cool. Disassembly is a delicate task in some cases. It is necessary to have a pair of fine tweezers and a balance brush: a Dumont INOX 3C tweezer and a No.7 Portrain brush are suggested. Specific disassembly instructions are included in the impactor sections.

6.2 DRYING AND WEIGHING

All collected materials should be dried in a convection oven at 212°F, desiccated until cooled to room temperature, and weighed to 0.01 mg. The weighing chamber of the balance should also be kept desiccated. The samples should be redesiccated for 2 hours and reweighed to establish constant weight.

NOTE: The above drying and weighing procedure determines the stage weights for use in final calculations. Normally, all samples should be weighed before the next scheduled test to ensure that impactor conditions are appropriate. Samples can be weighed immediately after clean-up for this purpose.

6.3 DATA LOGGING

Records should be kept in notebooks for all phases of the sampling program. It is generally easiest to keep three notebooks: one for recording weights which remains in the lab with the balance, and one each for recording the details on inlet and outlet sampling runs. A form incorporating the items in Table 2 is useful for recording the necessary information while sampling.

Table 2. SAMPLING INFORMATION REQUIRED

Date	Pitot ΔP
Sampling Location	Gas Velocity
Operator	Impactor Flow Rate
Impactor Identification	Nozzle Diameter
Run Code No.	Impactor ΔP
Port No.	Start Time
Probe Depth	Gas Meter End Time
Ambient Pressure	Total Sampling Time
Stack Temperature	Gas Meter Start Time
Stack Pressure	Meter Orifice Temperature
Impactor Temperature	Meter Orifice ΔP
Impactor Location in-stack/out-of-stack	Pressure at Meter Orifice
Scalping Cyclone(s)	

7.0 COMMERCIAL IMPACTORS

7.1 BRINK IMPACTOR

The Brink impactor is a low sample rate cascade impactor, suitable for measurements in high mass loading situations. A drawing with appropriate dimensions is shown as Appendix B. The information below supplements the more general discussion in the body of this manual.

Sampling Rate -- The usual sampling rates for the Brink are in the range of 0.04 to 0.07 acfm. The sampling rate must be low enough to prevent re-entrainment of particles from the lower stages. Normally, the last stage nozzle velocity must be less than 30-35 m/sec with ungreased substrates, and less than 65 m/sec with greased substrates.

Collection Substrates and Adhesives -- The Brink impactor collection stage is too heavy to use without a substrate. Foil cups are commonly preformed and fit into the collection cups of the Brink stages. If grease is to be used, the top stages require 5 or 6 drops of solution while the bottom stages normally require only one drop in the center of the cup.

Back-up Filter -- The Brink back-up filter is normally made of binderless glass fiber filter material. Two 1-inch diameter disks of filter material are placed under the spring in the last stage of the impactor. The filter is protected by a Teflon O-ring and the second filter disk acts as a support.

Brink Sampling Train -- Several Brink sampling train arrangements are available depending on the impactor used, flow rate, sampling time, etc. The original Brink design called for a system similar to that shown in Figure 4. The flow rate was determined by the pressure drop across the impactor. With the low flow rates found to be required for high particle concentration, it was very difficult to accurately measure the pressure drop across the Brink. Very low rates also precluded the use of a dry gas meter for sample volume measurement.

A better method of flow control and volume determination is to use a system built around a calibrated orifice as shown in Figure 5. To ensure proper measurement by the orifice and to protect the vacuum pump from damage resulting from condensation vapors, it is necessary to

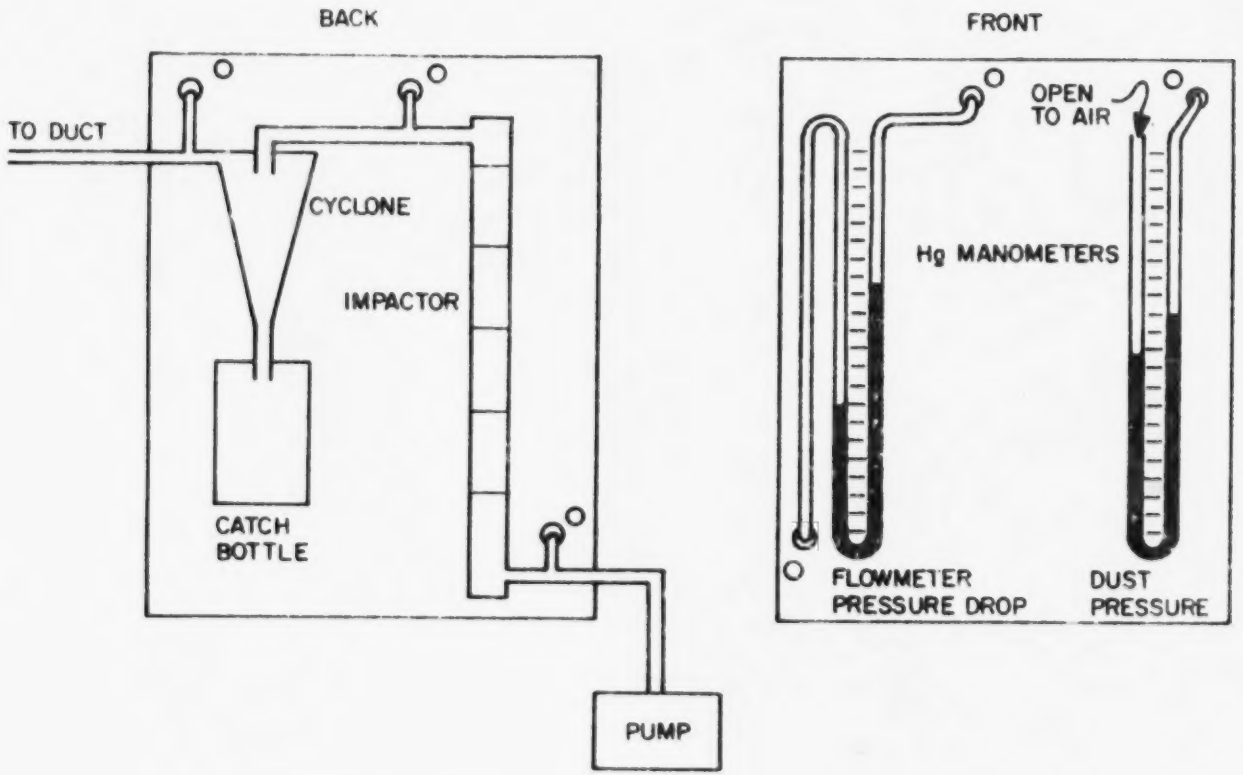


Figure 4. Original Brink sampling train, BMS II design.

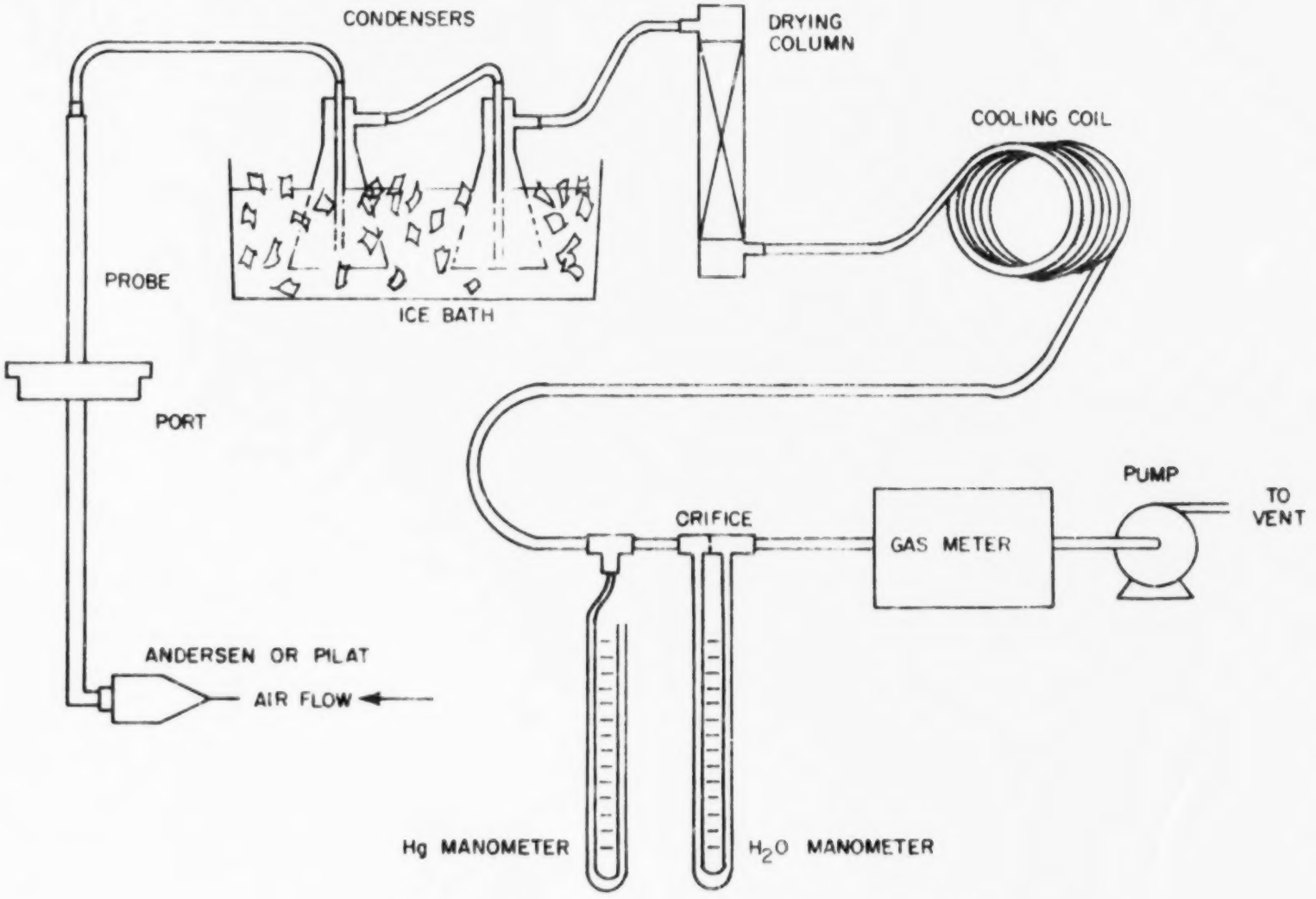


Figure 5. Brink impactor sampling train using a calibrated orifice flowmeter.

cool and dry the sampled gases after the impactor. For long sampling times, or where there is high water content, a series of condensers in an ice bath is useful for removing the water. A drying column and cooling coil are recommended to follow the condensers. Different size orifices (such as 0.03, 0.06, and 0.09 inches) allow for a wide range of flow rates with reasonable pressure drops using a water manometer. A Hg manometer is placed upstream of the orifice to determine the pressure at the inlet to the orifice. Orifice calibration calculations are included in Appendix A.

Brink Clean-up -- Careful disassembly of a Brink impactor is necessary for obtaining good stage weights. If a precollector cyclone has been used, all material from the nozzle to the outlet of the cyclone is included with the cyclone catch. All of this material should be brushed onto a small, tared, 1 x 1 inch aluminum foil square to be saved for weighing. Cleaning the nozzle is also important, especially if it is a small bore nozzle. All material between the cyclone outlet and the second stage nozzle is included with material collected on the first collection substrate. All appropriate walls should be brushed off, as well as around the underside of the nozzle, where as much as 30 percent of the sample has been found.

7.2 ANDERSEN IMPACTOR

The Andersen impactor is a relatively high sample rate impactor. Normal samples rates are about 0.5 acfm. The information below is specific to the operation of the Andersen impactor.

Sampling Rate -- The Andersen sampling rate is about 0.5 acfm. As with other cascade impactors, the flow rate must be low enough to prevent re-entrainment of impacted dust.

Collection Substrates and Adhesives -- Andersen substrates are obtained precut from the manufacturer. The substrates are glass fiber and of two types--one cut for the odd numbered stages, one for the even. As discussed earlier, normal Andersen substrates have a tendency to absorb SO_2 on basic sites in the substrate and therefore gain weight. The manufacturer has recently made substrates from a less reactive fiber material, and an effort should be made to obtain these if an SO_2 stream is to be sampled.

Back-up Filter -- The Andersen uses a 2-1/2 inch diameter disk placed above the final F-stage. The filter should be cut from binderless glass fiber filter material such as Gelman Type A Glass Fiber Filter Web or a material similar but resistant to SO_2 weight gain.

Andersen Sampling Train -- The Andersen sampling train is similar to the Brink system except for higher flow capacity in the pumping and flow measurement devices. Figures 6 and 7 are examples of high sampling rate trains. The pumping and metering systems of the commercial Method 5, EPA mass sampling train can also be used with the Andersen.

Care should be exercised never to allow a gas flow reversal to occur through the impactor. Material could be blown off the collection substrate onto the underside of the jet plate or the collection substrates could be disturbed. A check valve or maintenance of a very low form while removing the impactor from the duct avoids this problem.

Andersen Clean-up -- Cleaning an Andersen impactor is difficult. Foils should be cut to hold the substrates, and each foil and substrate weighed together before and after the run. For disassembly, the foil to hold the stage 1 substrate should be laid out. Next the nozzle and entrance cone should be brushed out and onto the foil. Then the material on stage 0 should be brushed onto the foil. The stage 1 filter substrate material should then be placed on the foil and, lastly, the top of the stage 1 plate O-ring and cross piece should be brushed off. Depending on how tight the impactor was screwed shut, some filter material may stick to the O-ring edge contacting the substrate. This should be carefully brushed onto the appropriate foil. This process is continued through the lower stages. Finally, the filter is carefully removed.

7.3 UNIVERSITY OF WASHINGTON MARK III (PILAT) IMPACTOR

The Pilat impactor is a high flow rate device with generally the same characteristics as the Andersen. The information below supplements that in the text.

Sampling Rate -- The Pilat sampling rate is on the order of 0.5 acfm. The flow rate must be low enough to keep scouring of impacted particles to a minimum.

Collection Substrates and Adhesives -- The Pilat Mark III has often been used with supplementary foil (aluminum or stainless steel) substrates.

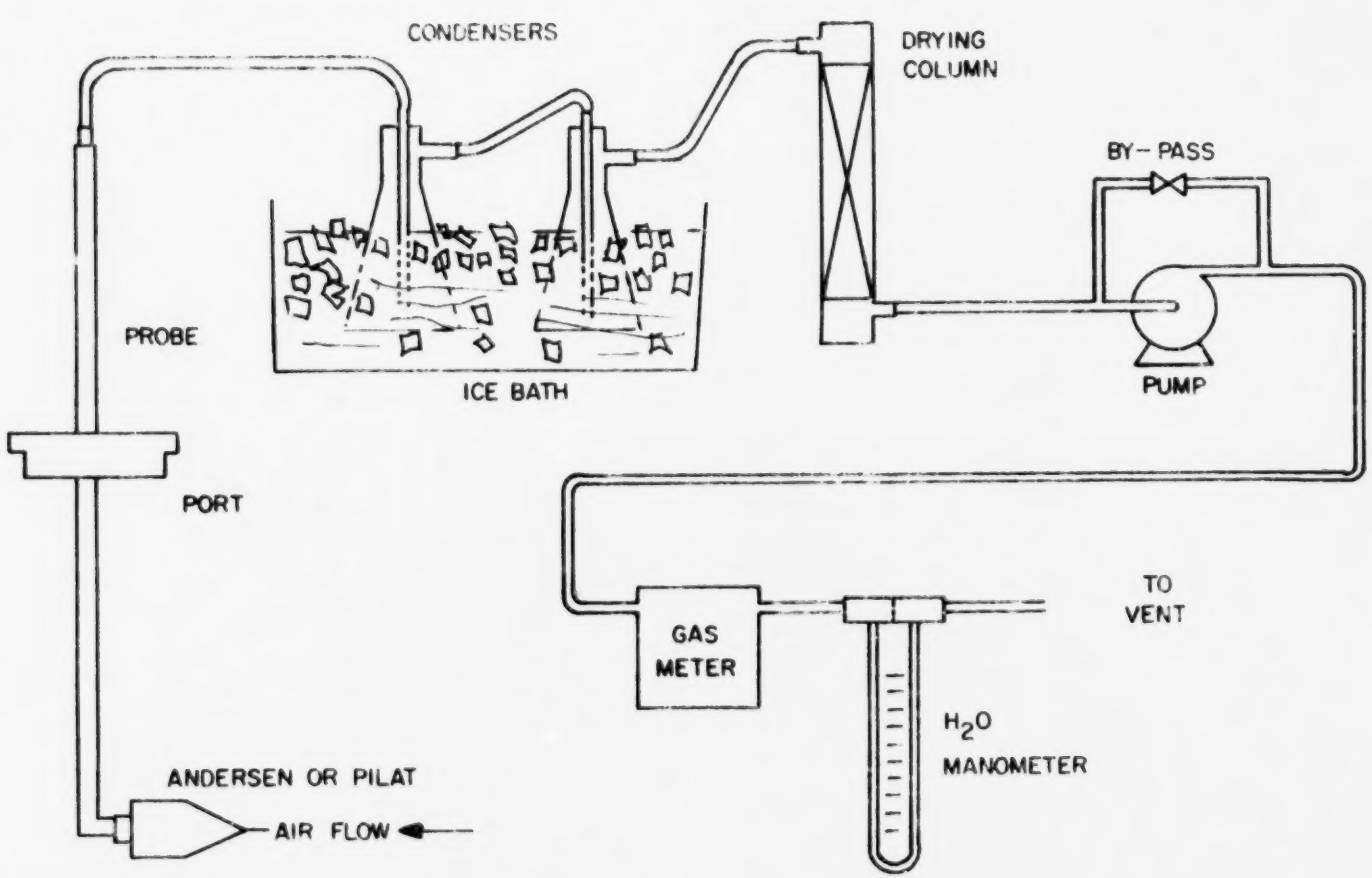


Figure 6. Andersen or Pilat sampling train with recirculation.

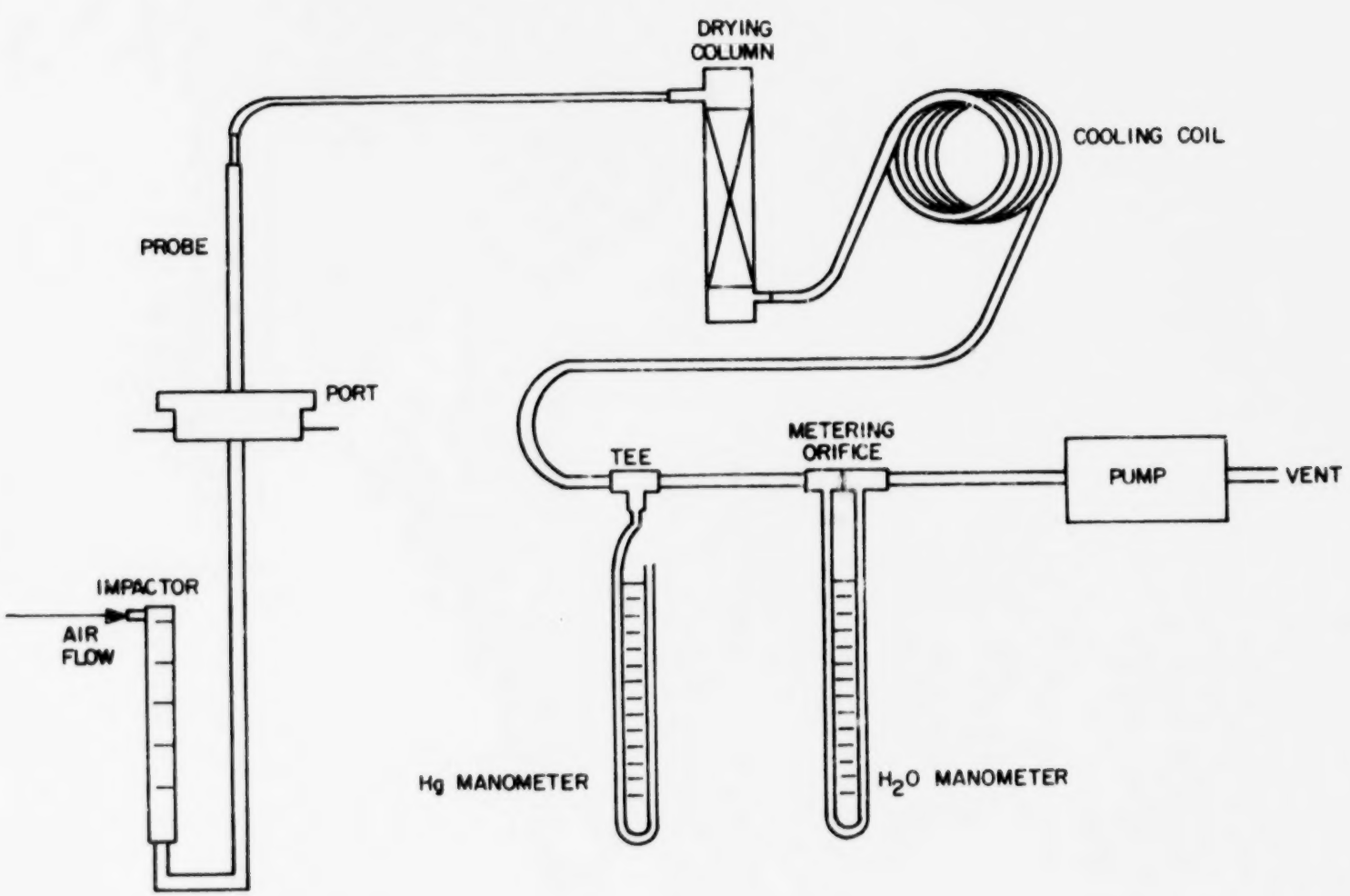


Figure 7. Typical Andersen or Pilat train using calibrated orifice and dry gas meter.

These substrates require the use of grease for most cases. Enough of the grease solution is placed evenly on the substrate to adequately cover the area under the jets (30 mg of grease). The normal cautions for the use of greased substrates apply as discussed in the text.

Pilat Sampling Train -- As the Pilat is a high flow rate device, its sampling train is similar to that of the Andersen. Figures 6 and 7 show examples.

Pilat Clean-up -- Pilat impactor clean-up is similar to that for the Brink. Some problems have been noted with O-rings sticking rather tenaciously and care must be exercised not to dislodge the sample while trying to separate the stages.

8.0 DATA ANALYSIS

8.1 CASCADE IMPACTOR DATA ANALYSIS

The information directly available from a cascade impactor is weight of particles on a stage. There are several ways to analyze and present this data as particle size distributions and fractional efficiencies. The increasing interest in particulate information has made it important that the data be analyzed using a standard method. Two methods are discussed below: the D_{50} method and the Picknett method.

8.2 D_{50} METHOD

The D_{50} method is presently used for the majority of cascade impactor data reduction. The method is fairly straight forward and can be hand-calculated, but it is a considerably simplified picture of the real distribution and can cause a loss of information.

The D_{50} of a stage is the particle diameter at which the stage achieves 50 percent efficiency; one half of the particles of that diameter are captured and one half are not. Figure 8 shows a complete set of theoretical capture efficiency curves for a modified Brink impactor. The D_{50} of stage 4, for example, is about 1.2 μm. The calculation of theoretical stage D_{50}'s is discussed below.

The D_{50} analysis method simplifies the capture efficiency distribution by assuming that a given stage captures all of the particles with a diameter equal to or greater than the D_{50} of that stage and less than the D_{50} of the preceding stage. With this simplification, the mass collected on a given stage can be assigned to a particular diameter; often the geometric mean of the stage D_{50} and the preceding stage D_{50} is used.

Particle-size distributions may be presented on a differential or a cumulative basis. When using the D_{50} method, either type of presentation may be easily employed.

The size parameter reported can be either aerodynamic diameter (that is, diameter based on the behavior of unit density particles) or approximate physical diameter, which is based on an estimate of the true particle density. In either case, the particles are assumed to be spherical. The method of reporting diameters depends to a large extent upon the ultimate use of the size distribution information. For this reason it is suggested that the data be reported in two parallel sets:

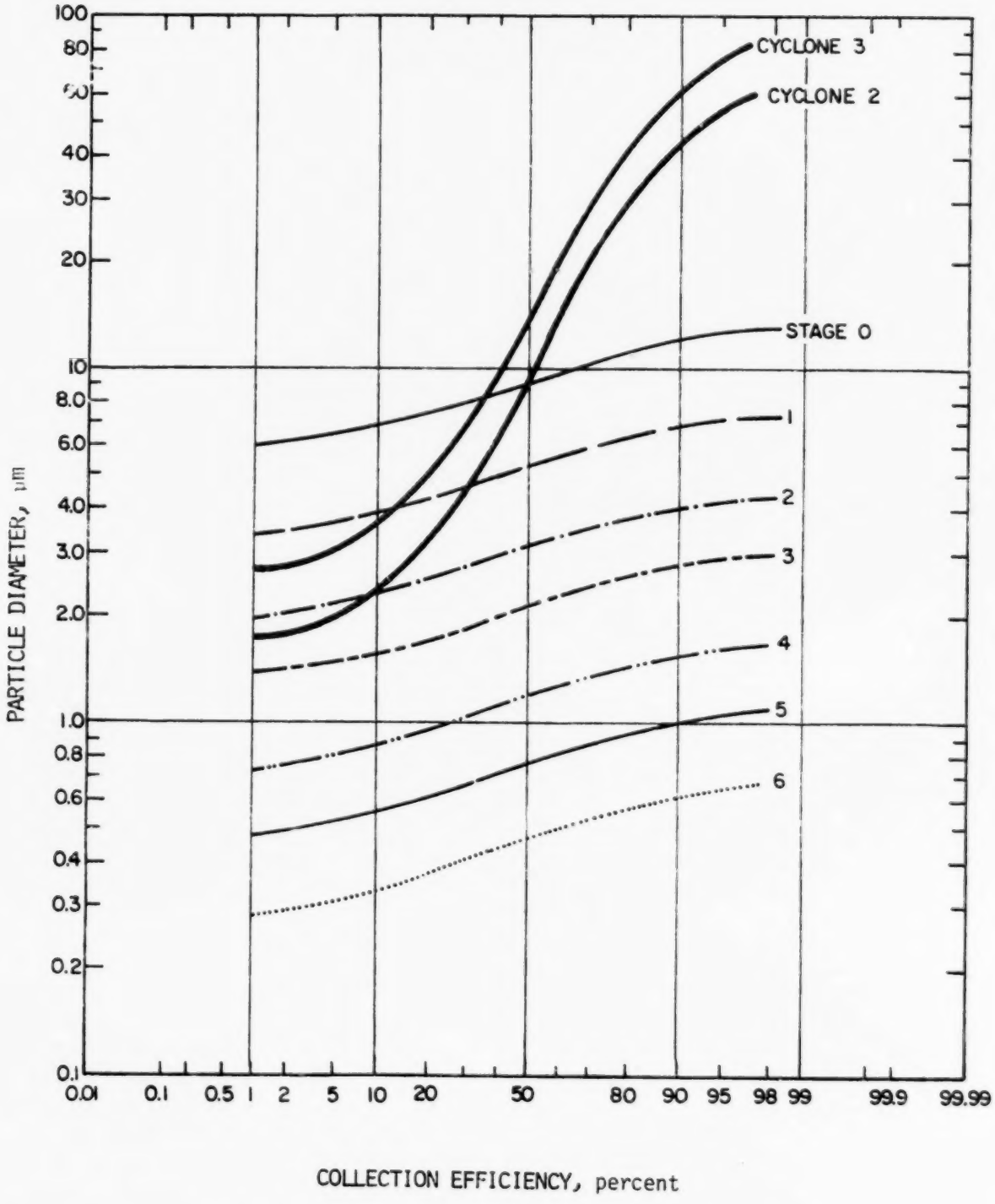


Figure 8. Stage collection efficiency for a modified Brink impactor (T=72°F, P=29.60 in. Hg. ρ=1.35 g/cm^3, flow = 0.03 acfm).

one set based on aerodynamic diameters; the other based on approximate physical diameters.

8.3 CALCULATION OF STAGE D_{50}'S - D_{50} METHOD

The reduction of field data obtained with a cascade impactor can sometimes be troublesome and time consuming because of the computations involved. The basic equation that defines the theoretical D_{50} of a given stage of a cascade impactor is:

$$D_{50} = 1.43 \times 10^4 \left(\frac{\mu D_c^3 P_s X(I)}{472 \rho_p Q_I P_o C} \right)^{1/2} \quad (1)$$

where:

$$C = 1 + \frac{2L}{D_{50} \times 10^{-4}} \left(1.23 + 0.41 \exp \left(\frac{-0.44 D_{50} \times 10^{-4}}{L} \right) \right) \quad (2)$$

D_{50} = stage cut point, µm

µm = viscosity of air at conditions immediately downstream of impactor jet(s), poise

D_c = diameter of impactor jet(s), cm

P_s = absolute pressure just upstream of jet(s), in. Hg

P_o = absolute pressure in stack, in. Hg

X(I) = number of holes in stage

ρ_p = density of particle, g/cm^3

Q_I = flow rate through impactor, acfm

C = Cunningham Correction Factor

L = mean free path of air molecule, cm

While these equations can in principle be solved rigorously when necessary, it is usually easier to solve them by trial and error.

One approach that can be used to further simplify the computations is to develop curves for the impactor stage cut points at one set of conditions; e.g., air at standard conditions and a particle density of 1.0. Then a suitable correction factor can be applied to these curves for the actual sampling conditions. Unfortunately, further simplifications are involved in making the correction factor simple enough to be of value. Therefore, the use of this type of approach suffers from some restrictions. Figure 8, presented earlier, shows a calibration for dry air at laboratory conditions with an assumed particle density of 1.35 gram/cm^3.

All of the assumptions and calculations involved in going from equations (1) and (2) to the calibration curve can be quite awkward, particularly in cases where different types of sources are being sampled. Perhaps the best approach is to write or obtain a computer program based on the rigorous equations given initially. The program can not only calculate impactor stage cut points but can also compute concentrations of particles in each size range, as well as differential and cumulative size distributions. It permits more sophisticated data reduction methods to be used than would be possible by hand. Manual calculation of cut points typically takes several hours. Using a computer program, several sets of data can be calculated in a few minutes. Not only is the computer faster but the possibility of computational errors is greatly reduced.

In summary, there are basically two ways that the computational difficulties associated with using the cascade impactor can be overcome. Where basically the same types of sources are being sampled, the calibration curve approach will work very well; however, in the general case where a wide variety of different types of sources are being sampled, the simplest approach is to use a computer program based on a rigorous solution of the cascade impactor equations.

8.4 DIFFERENTIAL PARTICLE SIZE DISTRIBUTIONS - D_{50} METHOD

It is assumed for the purpose of analysis that all of the mass caught upon an impaction stage consists of material having aerodynamic diameters equal to, or greater than, the D_{50} for that stage, and less

than the D_{50} for the next higher stage. For the first stage (or cyclone), it is assumed that all of the material caught has aerodynamic diameters greater than, or equal to, the D_{50} for that stage (or cyclone), but less than the maximum particle size. If the maximum particle size is not known, some arbitrary large value, say 100 μm, is used.

If the true particle-size distribution constituted a continuum, the amount of material having diameters between D and D+dD could be represented by dM. Then the integral

$$\int_{D_1}^{D_2} \frac{dM}{dD}\, dD$$

would yield the total mass having diameters between D_1 and D_2.

Because the intervals between the stage D_{50}'s are logarithmically related, and to minimize graphical scaling problems, the differential particle size distributions are plotted on log-log or semi-log paper with dM/d (log D) as the ordinate and log D as the abscissa. The mass on stage "n" is designated by ΔM_n and is, in approximation, the mass of particulate with diameter between $(D_{50})_n$ and $(D_{50})_{n+1}$. The Δ(log D) associated with ΔM_n is log $(D_{50})_{n+1}$ - log $(D_{50})_n$. Using these approximations, the derivative term associated with age "n" is:

$$dM/d(\log D)\Big|_n \approx \frac{\Delta M_n}{\Delta(\log D_{50})\Big|_n} = \frac{\text{Mass on Stage "n"}}{\log(D_{50})_{n+1} - \log(D_{50})_n}$$

Plotting this approximation of dM/d (log D) versus log D results in a histogram. From such a histogram, the total mass of particles with diameters between $(D_{50})_i$ and $(D_{50})_j$ can be calculated as the sum:

$$\text{Mass} = \sum_{\ell=i}^{j} \frac{\Delta M_\ell}{\Delta(\log D_{50})\Big|_\ell}\ \Delta(\log D_{50})\Big|_\ell$$

where "ℓ" takes on values corresponding to the discrete increments of the histogram.

If an impactor with an infinite number of stages were available, the histogram would approach a continuous function, the $\Delta(\log D_{50})$ terms would approach d(log D), and the mass between D_m and D_n could be calculated as:

$$\text{Mass} = \int_{D_m}^{D_n} \frac{dM}{d(\log D)} \, d(\log D)$$

Such an impactor does not exist, but the histogram can be plotted as a smooth curve by assigning some average of $(D_{50})_{n+1}$ and $(D_{50})_n$ to the $\Delta M/\Delta \log D_{50}|_n$ term. The geometric mean of the D_{50}'s is often used. This curve is then a continuous function approximating the actual particle size distribution. Such a curve is needed to calculate fractional efficiencies of control devices if the D_{50}'s differ for inlet and outlet measurements. The accuracy of the approximation is limited by the number of points, and by the basic inaccuracy of neglecting the non-ideal behavior of the impactors, especially overlapping collection efficiencies for adjacent stages.

8.5 CUMULATIVE PARTICLE SIZE DISTRIBUTIONS

The data may be presented on a cumulative basis by summing the mass on all the collection stages and back-up filter, and plotting the fraction of the mass below a given size versus size. This is frequently done on special log-probability paper. This paper may be preferable for interpretation, especially if the distribution is not log-normal. Cumulative distributions suffer from a couple of disadvantages when compared to differential distributions. An error in stage weight will be propagated throughout a cumulative analysis, but will be isolated by the differential approach. Differential analyses made of data taken over different size ranges can be compared, while cumulative plots of the same data may not be comparable because of differences in starting points.

When cumulative plots are used, the abscissa is the logarithm of the particle diameter and the ordinate is the percentage smaller than this size. The value of the ordinate at a given $(D_{50})_n$ would be

$$\text{Percent less than stated size} = \frac{\sum_{\ell=0}^{n} \Delta M_{\ell}}{\sum_{\ell=0}^{N} \Delta M_{\ell}} \times 100\%$$

where

ℓ = o corresponds to the filter,

ℓ = n corresponds to the stage under study, and

ℓ = N corresponds to the coarsest jet or cyclone

An analytical curve can be fitted to the cumulative distribution obtained above, and values of dM/d(log D) obtained by differentiation of the analytical expression. In general this requires some a priori assumptions in determining the form of the expression to be used in the curve fitting process, but several independent groups have used this technique to good advantage.

In spite of the shortcomings of the D_{50} method, it is attaining widespread use, partly because of the difficulty in establishing a better procedure. It is recommended that the D_{50} method be used, temporarily, and that the results be reported uniformly as dM/d(log D) versus D in micrometers. For convenience, this data is usually plotted on log-log paper in units of milligrams per dry standard cubic meter (mg/dsm^3). Both aerodynamic and physical diameters should be presented in each case.

8.6 PICKNETT METHOD

The Picknett Method is an alternate approach to particulate data analysis which approximates an actual particulate stream as a combination of monodispersed aerosols. The amount of each monodispersed aerosol is weighted so that the aggregate, if passed through an impactor, would be collected with the same mass fraction per stage as is the actual particulate stream. The capture efficiency with respect to diameter of each stage of the impactor must be known to use this approach. The discussion

presented below is introductory, and the reader should refer to the literature for a detailed discussion of the method (see Bibliography).

A given disperse aerosol, when directed toward the stage of an impactor, is partially retained. The fraction captured depends on the size distribution of the aerosol and the statistical capture efficiency of the stage; few of the smallest particles will be retained while most of the largest will be. As can be seen from Figure 8, a monodisperse aerosol which strikes the stage of an impactor is also only partially retained. For instance, only 50 percent of a 1.2 μm particulate stream would be retained by the Brink stage 4. If 50 percent of an arbitrary disperse aerosol was also retained by stage 4, a rough estimate of the dispersed aerosol particle size would thus be 1.2 μm. This principle can be extended by considering two monodisperse aerosols whose diameters bracket the diameter of the single monodispersed aerosol. Continuing the example above, the two monodisperse aerosols (with diameters "d<" and "d>") can be arbitrarily chosen as 1.0 μm and 1.5 μm in diameter. From Figure 8, the capture efficiencies at these diameters are, respectively, 0.25 ("E<") and 0.87 ("E>"). The relative mass frequencies of the two aerosols, which must add to 1.0, are "f<" and "f>". The total combination of the two monodisperse aerosols is assumed to be retained in the same fraction as the dispersed aerosol; in this example, one half of the aerosol must be captured.

$$(f<)(E<) + (f>)(E>) = 0.5$$

As stated above:

$$(f<) + (f>) = 1.0$$

Solving these two equations, we find that the fictitious combination of 1.0 μm and 1.5 μm monodispersed aerosols must contain about 40 percent of the 1.5 μm aerosol and about 60 percent of the 1.0 μm aerosol in order to model the dispersed aerosol.

Picknett has extended this principle to cascade impactors. An aerosol's behavior in an impactor with n stages is modeled with n+1

fictitious monodisperse aerosols. As part of the given aerosol is left on each stage in a cascade impactor, only that aerosol which reaches the next stage is considered in calculating the collection efficiency.

The Picknett method provides the mass frequencies of a group of fictitious monodisperse aerosols equivalent to the actual disperse sample. This information can then easily be converted to cumulative mass data. If desired, the continuous cumulative mass function can then be differentiated to achieve a differential distribution.

8.7 COMPARISON OF THE D_{50} AND PICKNETT DATA REDUCTION TECHNIQUES USING REAL AND SIMULATED STAGE LOADINGS

In investigating data reduction techniques it is difficult to separate inaccuracies in the theory and errors introduced by re-entrainment, bounce, scouring, and poor calibration of the impactors. This problem can be eliminated by simulating the capture of a fictitious aerosol using the efficiency curve shown in Figure 8. Once the stage loadings are calculated, this data is used to recalculate a particle-size distribution, using either the D_{50} or Picknett method, which should ideally be identical to the fictitious input distribution.

Figure 9 is a test of both the D_{50} and Picknett techniques, using a fictitious aerosol. The zero through 6 stages of the Brink impactor were used, and cyclone C_1, as shown in Fig.

It can be seen that both methods give very nearly correct values for the mass median diameter. The Picknett method is much better at the large particle end, because the D_{50} method does not account for the fact that the cyclone collects some particles which would otherwise reach the upper stages. The Picknett method does take this overlap in collection efficiencies into account, and gives a good "average" of the distribution, smoothing out the abrupt steps.

Figure 10 shows true and calculated particle-size distributions using actual experimentation stage loadings. An 8.3 μm diameter ammonium fluorescein aerosol was generated using a vibrating orifice aerosol generator. About 4 percent of the particles were found to be doublets (8 percent of mass). This time, we see that neither method approximates the real distribution accurately, although the Picknett method gives a good mass median diameter and better approximates the true size distribution than does the D_{50} method.

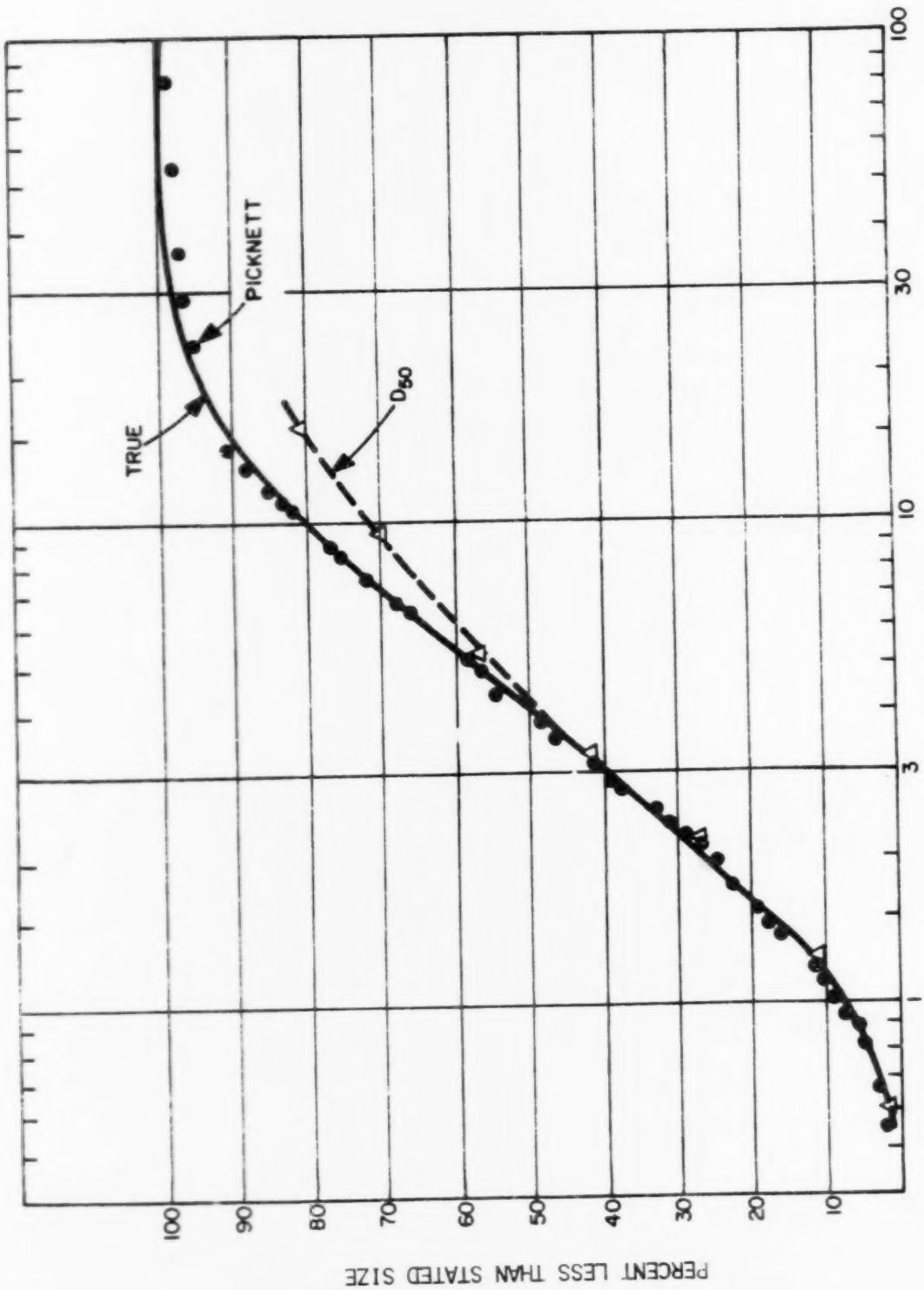


Figure 9. Simulation of a continuous particle size distribution.

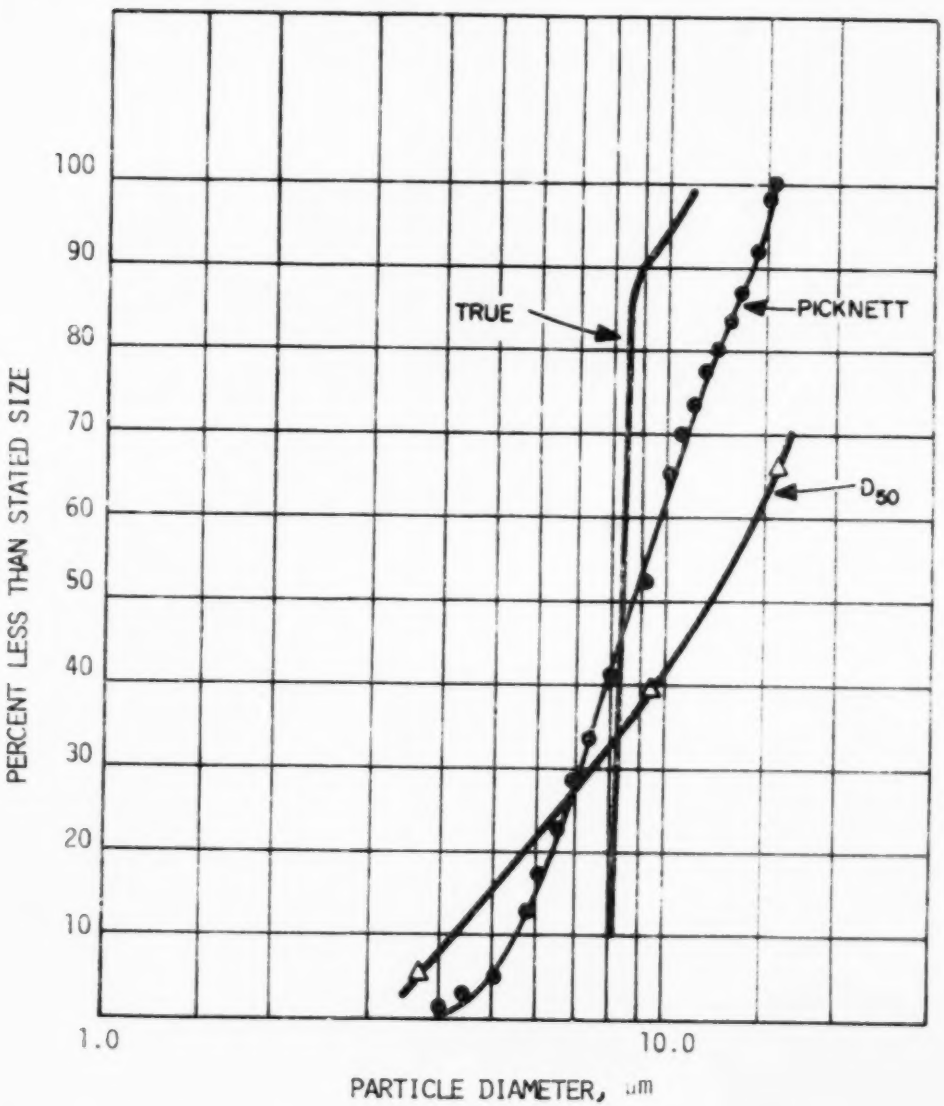


Figure 10. Comparison of D_{50} and Picknett methods.

In summary, the Picknett method has some advantages over the D_{50} method. It tends to give a more accurate model of the test aerosol. However, the D_{50} method is easier to use and can handle data which is somewhat scattered. The D_{50} method is also widely used and understood. If the Picknett method proves superior, then it, or a similar technique, should ultimately become the standard. The D_{50} method will probably continue to be useful as a quick way to get approximate results in the field.

9.0 BIBLIOGRAPHY

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3. Smith, W.B., K.M. Cushing, and G.E. Lacey, "Andersen Filter Substrate Weight Loss," Environmental Protection Technology Series, EPA-650/2-75-022, February 1975.

4. Smith, W.B., K.M. Cushing, G.E. Lacey, and J.D. McCain, "Particulate Sizing Techniques for Control Device Evaluation," Environmental Protection Technology Series, EPA-650/2-74-102-a, August 1975.

APPENDIX A

BRINK ORIFICE CALIBRATION

The use of a calibrated orifice to monitor the impactor flow rate involves the following equation, giving the pressure drop across the orifice water manometer:

$$\Delta P = \Delta P_0 \left(\frac{QI}{Q_c}\right)^2 (1 - F_{H_2O})^2 \frac{P_s^2}{P_0 P_c} \frac{T_0 T_f}{T_s^2} \left(\frac{MM}{MA}\right)$$

ΔP = calibrated orifice pressure drop, in. H_2O

ΔP_0 = pressure drop at which orifice calibrated, in. H_2O

QI = impactor flow rate chosen for isokinetic sampling,

Q_c = calibration flow rate for orifice

F_{H_2O} = volume fraction of water in the stack gas

P_s = ambient stack pressure $P_s = P_a + [\Delta P_s]$, in. Hg.

P_0 = pressure upstream of orifice referred to ambient, in. Hg

P_c = ambient pressure when orifice calibrated, in. Hg

T_0 = temperature of orifice, °R

T_f = temperature of the orifice when calibrated, °R

T_s = stack gas temperature, °R

MM = mean molecular weight of flue gas

MA = mean molecular weight of air

To monitor impactor flow rate with a dry gas meter either individually or in conjunction with a calibrated orifice, the following equation pertains:

$$Q_m = Q_s \frac{T_a}{T_s} \frac{P_s}{P_a} (1 - F_{H_2O})$$

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Q_m = flow rate indicated by the dry gas meter, acfm

Q_s = flow rate through the impactor at stack conditions, acfm

T_a = temperature of metered air, °R

T_s = stack gas temperature, °R

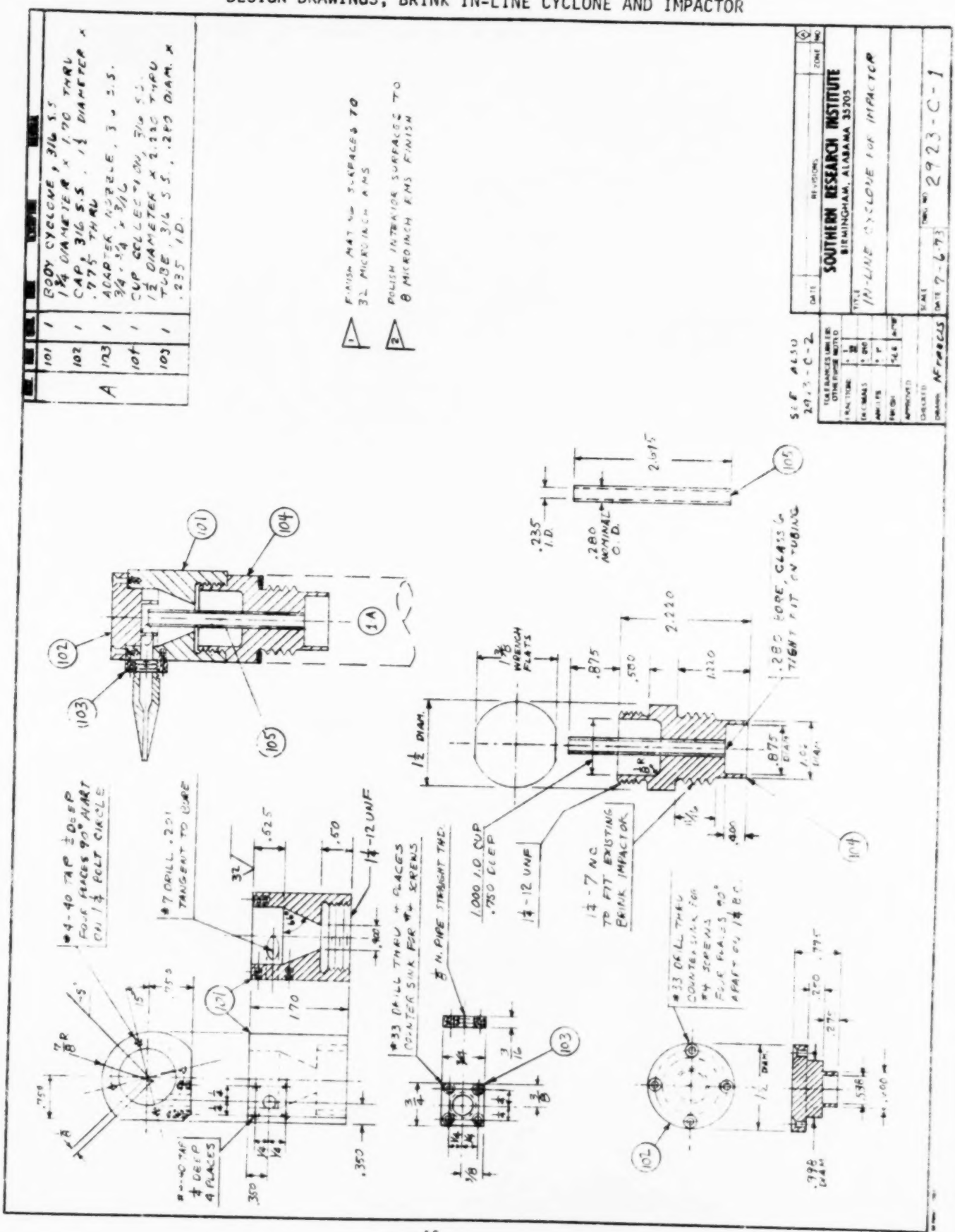
P_a = ambient pressure upstream of the meter, in. Hg

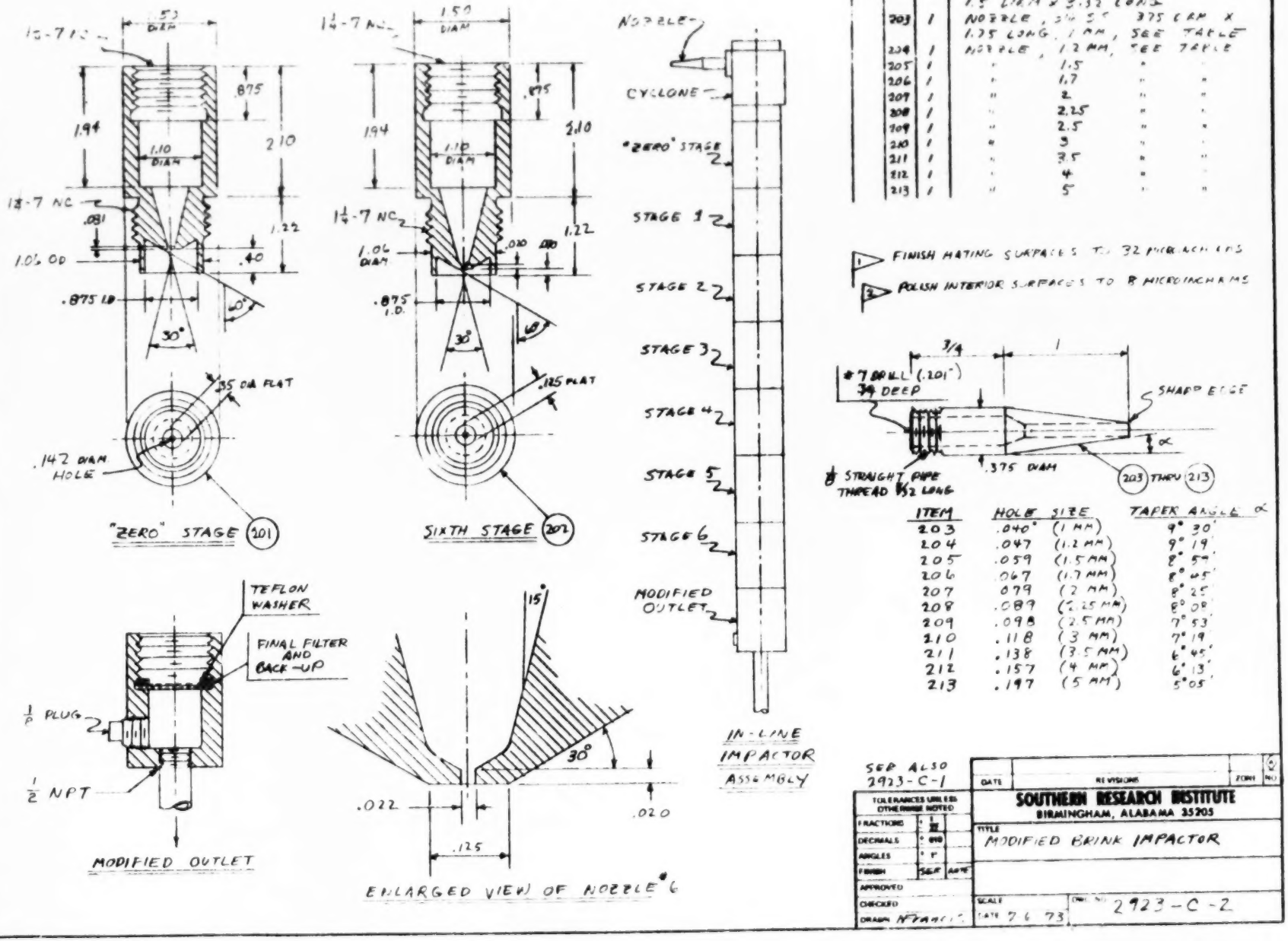
P_s = ambient stack pressure, in. Hg

F_{H_2O} = volume fraction of water in stack gas

APPENDIX B

DESIGN DRAWINGS, BRINK IN-LINE CYCLONE AND IMPACTOR


SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205
IN-LINE CYCLONE FOR IMPACTOR
2923-C-1
SEE ALSO 2923-C-2
101 1 BODY CYCLONE, 316 S.S. 1¼ DIAMETER x 1.70 THRU
102 1 CAP, 316 S.S., 1¼ DIAMETER x .375 THRU
A 103 1 ADAPTER, NOZZLE, 3 - S.S. ¾ - 14 x 3/16
104 1 CUP COLLECTION, 316 S.S. 1¼ DIAMETER x 2.330 THRU
105 1 TUBE, 316 S.S., .280 DIAM. x .235 I.D.
FINISH ALL SURFACES TO 32 MICRO INCH RMS
POLISH INTERIOR SURFACES TO 8 MICRO INCH RMS FINISH
#4-40 TAP ±DEEP FOR HOLES 90° APART ON 1¼ BOLT CIRCLE
#7 DRILL .201 TANGENT TO BORE
#33 DRILL THRU COUNTERSINK FOR #4 SCREWS FOUR HOLES 90° APART ON 1¼ B.C.
#8 PIPE STRAIGHT THD.
1.000 I.D. CUP .750 DEEP
1¼ - 12 UNF
1¼ - 7 NC TO FIT EXISTING BRINK IMPACTOR
1¼ DIAM.
WRENCH FLATS
.280 BORE, GLASS TIGHT FIT ON TUBING
.235 I.D.
.280 NOMINAL O.D.
2.615
2.220
1.220
.875
.500
.525
.50
.350
.170



	201	1	ZERO STAGE, 316 S.S., 1.5 DIAM x 3.32 LONG
	202	1	SIXTH STAGE 316 S.S. 1.5 DIAM x 3.32 LONG
	203	1	NOZZLE, 316 S.S. .375 DIA x 1.25 LONG, 1 MM, SEE TABLE
	204	1	NOZZLE, 1.2 MM, SEE TABLE
	205	1	" 1.5 " "
	206	1	" 1.7 " "
	207	1	" 2 " "
	208	1	" 2.25 " "
	209	1	" 2.5 " "
	210	1	" 3 " "
	211	1	" 3.5 " "
	212	1	" 4 " "
	213	1	" 5 " "

1 FINISH MATING SURFACES TO 32 MICROINCHES

2 POLISH INTERIOR SURFACES TO 8 MICROINCHES

ITEM	HOLE SIZE		TAPER ANGLE ∝
203	.040"	(1 MM)	9° 30'
204	.047	(1.2 MM)	9° 19'
205	.059	(1.5 MM)	8° 54'
206	.067	(1.7 MM)	8° 45'
207	.079	(2 MM)	8° 25'
208	.089	(2.25 MM)	8° 08'
209	.098	(2.5 MM)	7° 53'
210	.118	(3 MM)	7° 19'
211	.138	(3.5 MM)	6° 45'
212	.157	(4 MM)	6° 13'
213	.197	(5 MM)	5° 05'

SEE ALSO 2923-C-1

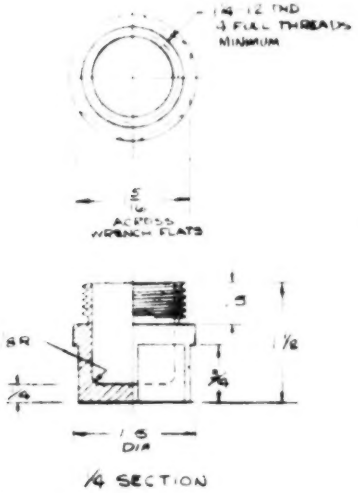
DATE	REVISIONS	ZONE	NO.

TOLERANCES UNLESS OTHERWISE NOTED
FRACTIONS ± 1/32
DECIMALS ± .010
ANGLES ± 1°
FINISH 32 RMS
APPROVED
CHECKED
DRAWN N. FRANCIS

SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TITLE: MODIFIED BRINK IMPACTOR

SCALE
DATE 7-6-73
DWG. NO. 2923-C-2

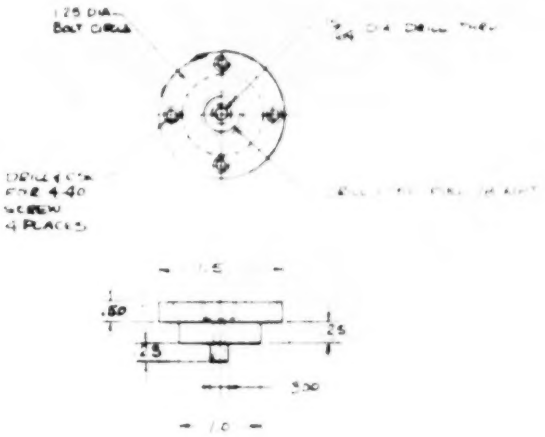


NOTES

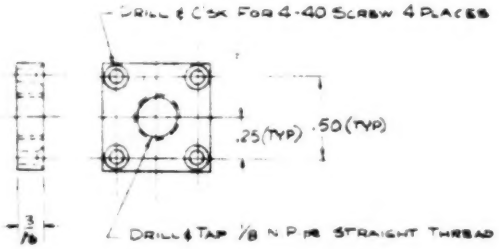
1. MAT'L - 316 STNL STEEL
2. POLISH INSIDE

1/4 SECTION

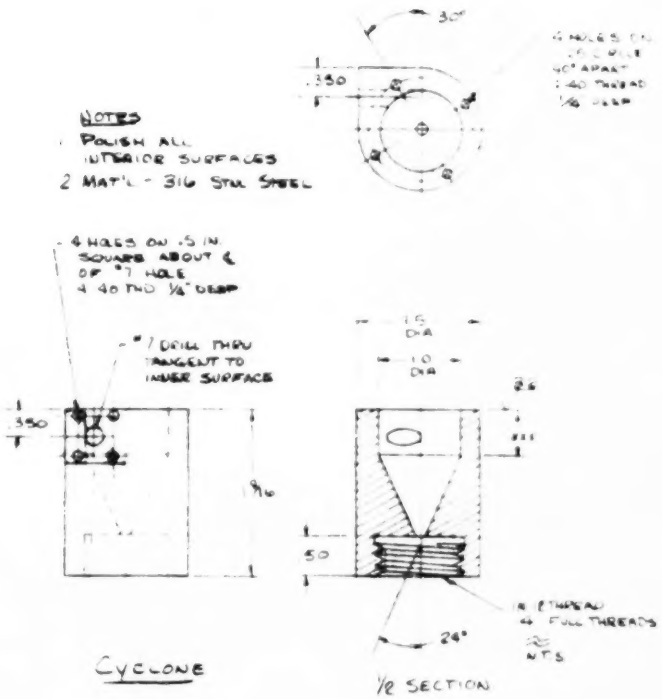
COLLECTION CUP



VORTEX TUBE AND OUTLET



NOZZLE ADAPTOR



CYCLONE

1/2 SECTION

COST ESTIMATING DATA SHEET

Quote No._____ Client_____

Job No._____ Date_____ Location_____

Purpose of Test_____

Type of Test - Particulate_____

Gases_____

Particulate Sizing_____

Auxiliary Analysis_____

PERSONNEL

COST ESTIMATING - PROFESSIONAL SERVICES

	Chemist/Engineers Meteorologist $_____/Hr.		Project Director Supv. Engr. $_____/Hr.		
	Hrs.	Cost	Hrs.	Cost	Total Cost
1.0 Pre-Survey					
1.1 Travel Time					
No. of Men					
2.0 Consulting					
3.0 Preparation of Test Protocol					
4.0 Preparation, Packing & Clean-up					
4.1 Construction Special Test Equip.					
5.0 Project Planning					
6.0 Field Test					
6.1 Travel Time					
No. of Men					
7.0 Lab Analysis					
8.0 Calculations & Report Writing					
9.0 Consulting & Design					
10.0					
11.0 Total					

Out-of-Pocket Cost
(See next page) _____

TOTAL COST _____

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Quote No._____ Client_____

Job No._____ Date_____ Location_____

COST ESTIMATING OUT-OF-POCKET EXPENSES

1.	Air Fare_____ Round Trips @ $_____ x_____ men	_____
	Air Fare_____ Round Trips @ $_____ x_____ men	_____
	Air Fare_____ Round Trips @ $_____ x_____ men	_____
2.	Vehicle Rentals_____	_____
3.	Shipping (Air Freight, Excess Baggage)_____	_____
4.	Per Diem_____ men x $_____/day x _____ days	_____
	Per Diem_____ men x $_____/day x _____ days	_____
	Per Diem_____ men x $_____/day x _____ days	_____
	Per Diem_____ men x $_____/day x _____ days	_____
5.	Limousine Service, Parking_____	_____
6.	Miscellaneous_____	_____
7.	Computer Time_____	_____
8.	Car Expenses ¢/mile x _____ miles_____ + tolls____	_____
9.	Trailer Expenses ¢/mile x _____ miles_____ + tolls____	_____
10.	Expendable Supplies_____	_____
11.	Special Equipment_____	_____
12.	General Supplies_____	No Charge

TOTAL: _____

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APPENDIX D

PRELIMINARY SURVEY

Name of Company _____ Date of Survey _____

Address _____ City _____ State _____

Name of Contacts _____ Title _____

_____ Title _____

_____ Title _____

Plant Telephone Number _____ FTS Number _____

Description of Process _____

_____

_____

_____

Operating Schedule of Process _____

Batch or Continuous Process _____

Feed Composition and Rates _____

_____

_____

Type of Fuel _____ Production Rate _____

Description of Air Pollution Control Equipment and Operation _____

_____

_____

_____

_____

_____

Safety Hazards _____

_____

Appendix D (Cont'd) Page 2 - Preliminary Survey

Assumed Constituents of Stack Gas for Each Sampling Site _____

_____

_____

_____

Possible Testing Sites (1) _____

(2) _____

(3) _____

(4) _____

Can Samples be collected of:

a. Raw Materials _____
b. Control equipment effluent _____
c. Ash _____
d. Scrubber water _____
e. Product _____
f. Fuel _____
g. Other _____

Signature Required on Passes _____ Waivers _____

Best Time to Test _____

Are the Following Available at the Plant?

a Parking Facilities _____
b. Electric Extension Cords _____
c. Electrician _____
d. Safety Equipment _____
e. Ice _____
f. Acetone _____
g. Distilled water _____
h. Weighing Balance _____
i. Clean-up Area _____
j. Laboratory Facilities _____
k. Sampling Ports _____
l. Scaffolding _____
m. Restroom _____
n. Vending Machines _____
o. Rope _____

1) Electricity Source

a. Amperage per circuit _____

b. Location of fuse box _____

c. Extension cord lengths _____ Quantity _____

d. Adapters Needed _____

2) Safety Equipment Needed

a. Hard hats _____ d. Safety shoes _____

b. Safety glasses _____ e. Alarms _____

c. Goggles _____ f. Other _____

3) Ice

a. Vendor _____

b. Location _____

4) Acetone

a. Vendor _____

b. Location _____

c. Telephone _____

5) Sampling Ports

a. Who will provide _____ Welder: _____

b. Size opening _____

6) Scaffolding

a. Height _____

b. Length _____

c. Vendor _____

Address _____

Telephone _____

7) Motels:

a. _____ Phone _____ Rate _____

b. _____ Phone _____ Rate _____

c. _____ Phone _____ Rate _____

8) Restaurants:

a. Near Plant _____

_____

b. Near Motel _____

_____

9) Airport Convenient to Plant _____ Distance _____

Comments:

Survey By: _____

APPENDIX E

STACK DATA SHEET

Properties of Sampling Locations	Stack #1	Stack #2	Stack #3	Stack #4
Purpose of stack				
Height, ft.				
Width, ft.				
Length, ft.				
Diameter, ft. I.D.				
Wall thickness, in.				
Material of construction				
Ports: a. Existing b. Size opening c. Size of platform				
Straight stack run before port, ft.				
Type of restriction				
Straight stack run after port, ft.				
Type of restriction				
Environment				
Work space				
Ambient temp., °F				
Avg. pitot reading in. H_2O				
Stack velocity, ft/min				
SCFM				
Moisture % by volume				
Stack temp. °F				
Particulate loading gr/SCF				
Particle size				
Stack pressure in. Hg				
Water sprays				
Dilution air				
Elevator				

Sketch of Stack to be Sampled Showing Locations of Port Openings, Water Sprayers, Flow Interferences, Dilution Air Inlets, and Scaffolding or Platform Erection Dimensions.

APPENDIX F

SAFETY CHECKLIST

Date _____

Company _____

Location _____

A. MEDICAL:

1) Plant first aid available (yes/no) _____.
If available give location of unit and telephone number

_____

2) Phone number for ambulance _____

3) Phone number for hospital _____

4) Comments: _____

_____

B. TEST SITE CHECKLIST: Check if OK.

1) Ladders:
General conditions _____, rest stops _____, cage _____
Comments: _____

_____

2) Scaffolds/Platforms:
General conditions _____, guardrails _____
toeboards _____, screening _____
Comments: _____

_____

C. PERSONNEL PROTECTION EQUIPMENT: Check if needed.

1) Safety glasses _____, side shields _____
face shields _____, goggles _____, hard hat _____,
safety shoes _____, electrical hazard shoes _____,
life belt and safety block _____,
hearing protective devices _____, ladder climbing devices _____

2) Respiratory equipment:
Air purifying _____, air supplied _____,
self-contained _____,
Other _____

_____

3) Body protection:
Chemical protection garments _____
Heat protective garments _____
Chemical gloves _____
Heat resistant gloves _____
Other _____

_____

D. ARE FIRE EXTINGUISHERS AVAILABLE AT SITE _____?

E. SPECIAL OR UNUSUAL TEST PROCEDURES AND SAFETY PRECAUTIONS NECESSARY:

_____

_____

_____

_____

APPENDIX G

METRIC SYSTEM CONVERSION FACTORS

Non-metric	Multiplied by	Yields Metric
acfm	28.317	liters/min
°F	5/9 (°F-32)	°C
in.	2.54	cm
gr/acf	0.0023	g/liter